SANDERS ASSOCIATES

High Temperature Solar Receiver

Final Report

for the period

7 June 1979 - 7 April 1981

" This work was performed for the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration."

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Index

1.0 EXECUTIVE SUMMARY

A High Temperature Solar Thermal Receiver has been developed by Sanders Associates of Nashua, NH under the terms of JPL Contract 955454. Initial concept analysis and development occurred during the second semester of 1979. Then under terms of a contract modification issued in the spring of 1980, a prototype receiver and associated test support (auxilary) hardware was fabricated. Sanders and JPL personnel performed shakedown and initial performance tests of the prototype receiver at Edwards AFB, CA at the JPL Parabolic Dish Test Site between 14 October 1980 and 13 December 1980. Maximum outlet temperatures of 1600 F were achieved at 100% solar (70-75 kW) input power with 900 F inlet temperatures. Subsequent testing by JPL (Hanseth) was concluded by a 2550 F outlet run on 6 February 1981.

Window retention problems were experienced during early testing, so the window retaining assembly was modified to improve its tolerance of thermal distortion of the flanges. Subsequently, the overall integrity of the design has been validated. The receiver has since been operated at 2550 F, marking achievement of the design goal temperature (of 2500 F). The Sanders/JPL Receiver has shown that cost effective receiver designs can be implemented within the framework of present materials technology.

There is now the opportunity to exploit this technology with the application of the receiver to the distributed system task, i.e., couple the receiver to a turbine/recuperator and generator to demonstrate power generation and proceed with a productionizing of the receiver design to reduce production cost and weight. Both these tasks are essential to the early deployment of economic alternate energy systems.

2.0 SUMMARY

2.1 Prior Activity

The Energy Systems Center of Sanders Associates, Inc. and JPL have concluded the preliminary testing of the High Temperature Solar Receiver at Edwards AFB, CA. This testing was conducted in accordance with the terms of the most recent negotiation of JPL Contract 955454. The initial charter of the contract called for the study of High Temperature Receivers in general and concept development of a viable candidate in particular. Sanders concluded that study phase in December 1979 and recommended development of a prototype receiver with a windowed aperture and ceramic matrix. The recommendation was accepted and the contract was accordingly modified.

The prototype development and test phase of the contract included receiver redesign as necessary to interface with the Test Bed Concentrators at Edwards AFB and the design of the requisite auxiliary equipment to run the performance tests.

The design work commenced late in the spring of 1979. After a design review in June, fabrication, assembly, and ground test of the equipment was performed at the Sanders Defensive Systems Division in Merrimack, NH.

The High Temperature Solar Receiver and its auxiliary equipment was shipped to JPL at the Edwards Test Site on 15 October accompanied by test support personnel. Installation of the receiver and initial hook-up of the instrumentation was accomplished by midday of Friday, 24 October 1980 by the combined efforts of the ETS personnel and the Sanders personnel. During the afternoon of 24 October, a brief flow test was conducted to check system control performance. Flow control instability was noted and the flow test was concluded. Sanders personnel (SB Davis and P Foley) returned to NH to resolve the flow problems. Investigation of the phenomena indicated the control instability was induced by control system 'lag'. Lag is a response delay caused by excessive sensing and control line length between controller and its slave valve. Corrective options were developed and evaluated.

Davis returned to Edwards on 10 November and performed a field conversion of the Fisher 4150R pneumatic controller to a 4151R remote loading configuration. This change along with the installation of a remote loading panel in the control console corrected the flow control problems.

Subsequent effort at Edwards consisted of correcting several minor instrumentation (primarily thermocouple) problems and preparing for solar tests. During the period from 10 to 25 November 1980, the above tasks were performed, non-solar system preheat tests were conducted, and finally a 25% solar test was attempted on Tuesday, 25 November.

That test was terminated when the window failed; subsequent inspection of the hardware showed that the solar tracker had directed the focused energy onto the window retainer flange causing the failure. The test activities were suspended over the Thanksgiving holiday and Davis returned to the East where the test was reviewed by management. Appropriate repair work was prescribed and Davis returned to the West with replacement hardware. Testing was resumed on 1 December 1980. On Wednesday, 3 December gross tracking offset corrections were entered into the TBC control routine. An insulation mask was added to the aperture to protect the window retainer (flange).

On Thursday, 4 December a preheat test to 1700 F was conducted and the refurbished window and flange survived. On 5 December the 25% solar test was successfully conducted and the window survived. On Monday, 8 December the concentrator was configured to 50% and another successful test was conducted. On Tuesday the concentrator was configured to deliver 100% power. That test was terminated when the focused

energy melted through the water cooled slide plate. The slide plate assembly was replaced the following morning and the test was repeated. Alignment of the solar flux with the aperture was good (probably aimed low by only 3/8 inch) and well centered. The receiver ran well for 4 minutes and 30 seconds at which time a crack was observed propogating in the window. Pressure was reduced and the test was terminated.

Inspection of the hardware showed the flange had coned inward and had then fractured the window over the edge of the support flange. The window retention scheme was altered to eliminate mechanical interference beneath the window.

This modification provided the necessary clearance to accommodate thermal distortion of the window retainer flange without inducing window failure. During the afternoon of Thursday, 11 December 1980 entry of minor aiming offsets was attempted with uncertain results. The receiver was then tested at 100% solar flux. The receiver was run 'on sun' for 1 hour during which time the exhaust air temperature rose from 900 F to 1600 F. No apparent window degradation was observed during post test inspection of the receiver. The internals of the receiver (solar) cavity were inspected and showed no deterioration.

The window problems encountered during the above test sequences were the product of initially insufficient clearances being provided for thermal distortion and insufficient shielding of the window retainer flange from spilled solar flux.

On Friday, 12 December 1980 a short review meeting was conducted at Pasadena (JPL) to consider progress to date, solve niggling problems, and plan subsequent testing. Outcome of the meeting is listed below.

1. Window clamping configuration appears vastly improved and should function up to 2200 F (and may be suitable up to 2500 F.)

2. Testing on the receiver will be conducted between 15 and 23 December 1980 by JPL (Hanseth) in an attempt to demonstrate high temperature performance and collect characterization data.

3. Sanders recommends additional testing be performed after 1 January 1980 to more fully characterize the receiver throughout its entire design range.

4. JPL should have Sanders procure additional windows and exhaust aperture plates to assure the test program can be completed without hardware delays. Since the TBC availability is nominally scheduled until the end of January 1981, and since occasional window breakage may

occur until details of the window support are fully resolved, the lack of windows could delay testing if extras are not procured beforehand. New exhaust apertures should be provided to permit testing in the high mass flow regimes.

5. Sanders (Davis) should be available for consultation or field test support on an as needed basis until the conclusion of the testing program.

6. Sanders should participate as a presenter at the JPL Annual Review to publish results of the HTSTR effort and test. The favorable publicity of a successful test program will derive benefits to the Distributed Systems Effort.

2.2 Recent_Activity

During the period between 15 December 1980 and 11 February 1981 additional HTSTR testing was conducted and the 12 December 1980 meeting items were implemented as noted below.

1. The new window clamping configuration performs satisfactorily and has been successfully operated at matrix oulter temperatures near 2550 F.

2. The receiver has exceeded outlet temperature goals during recent testing. Characterization of the receiver has been deferred due to budget constraints, but remains an important goal.

3. Funding should be provided to reduce and analyze the collected data. Insufficient testing has been conducted to date, but preliminary test data certainly justifies additional performance (characterization) testing and in-depth data reduction. We know we have something good; but just how good is it?

4. New windows have been procured and will be forwarded to JPL as needed. The second HTSTR may be assembled shortly for use as a GFE receiver for EE-2A.

5. Numerous interactions have occurred and have proven mutually beneficial.

6. Sanders will present (the Executive Summary) to the upcoming SERI conference in Oakland on Thursday, 9 April 1981.

3.0 RECOMMENDATIONS

3.1 Current Effort

The JPL designed water-cooled aperture plate should be modified to shield the window retainer flange from incoming solar flux.

Additional testing should be authorized to permit mapping of receiver operating characteristics and efficiency over its design operating range.

Additional testing should be conducted during the present installation of the receiver on TBC-2. Since the removal and subsequent reinstallation of the receiver will entail approximately (three weeks of effort), testing of the receiver during the present installation would save three weeks effort which could be better expended collecting performance data rather than handling equipment and trouble shooting instrumentation.

3.2 Support Effort

Flux at the receiver (aperture plane) should be mapped to permit accurate assessment of receiver efficiency. As a minimum effort, the data which was collected after TBC-2 was "cross-aimed" should be made available for evaluation. for ul, [illegible]

3.3 Additional Scope Effort

Program scope should be extended on two fronts to capitalize on the results achieved to date.

3.3.1 System Demonstrations -

The prototype receiver should be coupled to a Brayton engine to demonstrate the state of development and the near term realization of solar-thermal-electric conversion capability of distributed systems.

3.3.2 Production Designs -

The receiver design should be productionized to obtain the benefits of reduced weight and cost. The production receiver should be tailored to a specific engine application and should be apertured for lower cost concentrators.

4.0 TOPICAL RECORD OF ACCOMPLISHMENTS

4.1 Assembly And Installation

Upon completion of ground testing at Sanders, the system components were broken down into major sub-assemblies and shipped with replacement parts and tools to Edwards Test Site (ETS) in (7) crates. Transportation was via truck to Boston, air freight to Los Angeles, and truck to ETS.

Inspection at ETS showed the system (and particularly the receiver) had survived the trip well. Some minimal loosening of the ceramic honeycomb panels was observed, but structural integrity of the receiver was not adversely affected. After inspection the receiver and auxiliary preheater were mated and prepared for mounting in the TBC.

On Monday, 20 Oct 80 an Air Force crane was provided to lift the receiver into position on the TBC. Installation was accomplished without difficulty. Interface of the receiver and TBC was virtually flawless and the lift was completed within 2-1/2 hours. The rear mounting surface of the TBC has one channel slightly out of plane; the anomaly offsets the receiver less than 3/8 inch in the mounting ring.

The remainder of the week was consumed running cables through conduits. Actual cable pull was accomplished on Thursday and Friday, 23-24 October. The ETS crew managed to complete installation of air lines and water cooling lines, but their principal priorities were directed toward the O-G and TBC-1 steam receiver projects.

During the early phases of the installation and test difficulties were experienced in getting the support necessary to the expeditious accomplishment of the assigned tasks. This test represented the first occasion involving on-site support by a vendor. Established procedures and organizational hierarchy did not anticipate the needs of such test support

activities. JPL, however, soon grasped the situation and instituted certain organizational and procedural changes which significantly improved the level of support. Site personnel were well qualified and fully cognizant of the intricacies of their site. They were cooperative at all times and gave maximum support consistent with their organizational priorities. Support from the instrumentation group was excellent throughout the effort and demonstrated the professionalism of an adequately staffed and well motivated group.

4.2 Instrumentation

The Parabolic Dish Test Site (PDTS) is well equipped and prepared for its task of supporting the engineering development tests conducted there. The instrumentation and data collection system represents a network without which a test facility such as PDTS could not effectively operate. The readiness and flexibility of the PDTS instrumentation system to interface with the (Sanders) experiment was of key importance to the successful conduct of the receiver tests.

Fifty-one (51) channels of thermocouple data and 26 channels of (transducer) voltage data was collected using the PDTS automated data collection system. Connection and checkout of the instrumentation represented the largest single effort of the test support activities preparatory to the

actual conduct of the solar tests.

Functional check-out of the thermocouples was complicated by the use of shielded K-type thermocouples in the receiver and preheater. The chromel/alumel leads in the shield are not marked, so an ambiguity exists when the TC's are connected to extension wire. This ambiguity may be detected when the system is heated, but it is not evident beforehand. Voltage transducers are more easily installed and checked, but there are numerous interconnections to make. All this activity is further complicated by the fact that most work must be done at or near the focal point, twenty feet above the ground. Access to the equipment is via scaffolding or mobile manlift.

Then the proper channel assignments, data-logger configuring, and system end-to-end performance checks must be completed. The total on-site intrumentation interfacing effort represents a busy 2-3 week undertaking.

All data was collected through the Autodata 9 and then written to magnetic tape for storage. A few algorithms were incorporated to convert raw signals of voltage to engineering units of pressure and mass flow. Data channels were scanned and recorded 4 times per minute during the solar tests. Minimal data reduction has been accomplished to date due to funding limits.

4.3 Controls

The control system for the receiver had been well checked during ground test at Sanders prior to shipment west. Accordingly, most of the on-site effort applied to the control system was for cable installation and feedback thermocouple hookup. Electrical cables had been preassembled and functionally checked at Sanders, so there were no surprises at ETS.

The pneumatic control system was affected by the difference in the lengths of plumbing runs and did require some on-site modifications. As originally configured and tested at Sanders, receiver pressure was regulated by a proportional valve installed in the interface box between the compressor and receiver. The compressor/valve line and the valve/receiver lines were 20' and 15' long respectively. The valve was, in turn, controlled by a (Fisher 4150R) reverse acting proportional controller which was mounted on the control console. Communication between the controller and valve was via three 15' long x 3/8" diameter flexible tubing lengths.

At the PDTS the compressor/valve line was 235' long. The valve/receiver line was 200' long. The three pneumatic control lines (between the interface box and control console) were each 200' long.

On Friday, 31 Oct 80 the first flow tests at ETS were conducted and flow control was unsatisfactory; the system oscillated with a 3 to 4 second period. The test was discontinued and the problem noted. The Sanders crew (Davis and Foley) returned east. During the following week Fisher was contacted and the problem was diagnosed as lag, a condition wherein a phase angle approaching 90 degrees develops and instability occurs. Fisher representatives offered hardware which might alleviate the problem_relays or volume boosters_but the ultimate solution which could be implemented at much less cost was devised by Sanders. Upon returning to ETS on Monday, 10 November Davis initiated a field modification of the 4150R controller to a remote loading configuration equivalent to the 4151R. The fix avoided delivery delays which would have been experienced had we procured boosters or relays. The modified controller was moved from the control console to the interface box in immediate proximity to its proportional slave valve. A remote loading panel was installed in the control console and utilized the three existing pneumatic tubes to communicate to the (now modified) controller. These modifications were completed and the system tested stable by Wednesday, 12 November. The system flow tended to "hunt" due to the long main flow lines, but that was corrected by opening the proportional valve to 60%. In effect, the controller gain was decreased to allow very steady operation, albeit with some

additional droop. There are no adverse effects as the operator has full control and pressure readout at the control console. Subsequent testing was conducted without difficulty in this configuration. No other control difficulties were encountered.

Expansion of the test program to map receiver performance would allow some experimentation with temperature controller parameters to optimize their performance. As it is now, the controllers are running without "reset", so they develop some droop_on the order of 10-20 F. That droop is effectively eliminated by manual application of load line adjustment. The microprocessor based controllers offer extreme operational flexibility and convenience; incorporation of a reset function is accomplished by keyboard entry from the face of the unit. This minor adjustment has simply been deferred in the interest of collecting maximum data in a time constrained test schedule. Determination and setting of the correct reset parameters can be accomplished in a couple hours of preheat testing.

4.4 Window

The receiver aperture is sealed with a quartz window. the window concept was subjected to extensive analysis to determine temperature and stress profiles under the combined loading of solar flux, cavity reradiation, and differential

pressure. Analysis showed the cavity radiation induces the largest portion of the window stresses when the receiver is operating at maximum temperatures (2200-2500 F). Pressure loading produces nominal stresses which by themselves are not likely to cause window failure. Analysis of the solar flux absorption based on (GE-type 124) quartz transmissivity, showed heating from solar is not a problem. Spectral transmissivity of the quartz reportedly does not change significantly at temperatures below the devitrification point. This background information is presented to provide a perspective for the evaluation and appreciation of test results to date.

Tests were run at Sanders during which the receiver was pressurized to 3.0 atmospheres (absolute) and inlet temperature was 1700+ F. Solar tests with 100% mirror exposure have been run at receiver outlet temperatures of 2550 F. Peak fluxes of approximately 500 w/cm2 have been transmitted through the window without apparent window degradation. In view of these achievements, the fundamental issues of window suitability to the application have been answered affirmatively.

A number of windows have broken during the test sequence. Inspection of the failed parts and mounting flanges indicate the window failures were caused by interferences and stress concentrations related to flange design or tracking errors.

These problems are amenable to corrective action and do not represent fundamental problems with the windowed receiver concept. A chronological summary of window performance is presented below.

1. 8 Oct 80. Instrumented window failed when installed with strain gage lead pinched by flange. Attributed to personnel error.

2. 20 Nov 80. Replaced instrumented window with new window in preparation for first solar test. This window was observed to be broken after a preheat run, so it was inspected to determine why the failure had occurred. A list of the reasons advanced is presented below.

    1. Window mounting surfaces were not clean of all foreign objects due to hasty window change. Personnel error.

    2. Window retainer flange was over-tightened.

    3. Loss of cooling air due to failure of tygon cooling air line. (This was not detected until 25 Nov 80.)

    4. Rapid preheating and cooling of window without first "aging" it to relieve residual stresses.

    5. Faulty window

6. Diminished window cooling due to extension of cooling plate.

7. Vibration induced by slide plate.

8. Exposure of window to cold night air.

Relative probability of the failure modes was assessed, and corrective or preventive measure were prescribed where indicated. The corresponding list of action items is presented below.

1. Used extreme caution during reassembly to remove all foreign objects from the window mounting surface. Cleaned flanges and buffed copper window gasket.

2. Reduced flange preload and torqued retainer flange bolts evenly to 10 inch-pounds.

3. This fault went uncorrected as it had not yet been detected. Failure was noted on 25 Nov 80 and was subsequently corrected.

4. Used gentle preheat rate of about 50 F/minute.

5. Inspected both the fractured window and its replacement. The windows exhibit numerous bubble inclusions but do not have surface blemishes.

6. Normally operated with slide plate in the retracted position. The plate is extended only during the critical phases of slewing on/off sun when the solar flux would impinge on the retainer flange.

7. No action, mode considered low risk.

8. No action, mode considered low risk.

3. 25 Nov 80. Slewed on sun for first 25% solar test. Window failed after approximately 45 seconds. Spot was observed to be aimed approximately four inches to right of center of aperture. Discoloration of window retainer flange was noted and window subsequently cracked. System was slewed off sun. About two minutes later the window failed catastrophically. Shrapnel blew out and window fragments damaged 4 TBC panels. This window failure was caused by the misdirected solar flux impinging on the right side of the retainer flange. The flange warped and broke the window. The lack of cooling air may have contributed to the rapid failure. A replacement flange and window gasket were used to refurbish the receiver. The window support flange (the inner flange) was inspected and found to be warped with a 5 mil high spot at 3 o'clock. The copper gasket was replaced with a more compliant asbestos (Garlock 900/7735) compound gasket. An insulation mask of Saffil 3000 was fabricated to shield

the window retainer from the impinging flux. The mask was held in place by the water cooled (JPL supplied) aperture plate.

4. 5 Dec 80. Ran succesful 25% solar test. Window survived. Window appeared to be very reflective during test. After test the window was inspected and found to be dirty but much less so than it appeared during the test. The window was removed and thoroughly cleaned prior to reinstallation for the next test. The residue on the inside was sooty and probably derived from the rich combustor start which had been experienced. Residue on the outer surface appeared to be a cooked on deposit from oil and water in the cooling air_humidity had been running near 50% during storm passage.

5. 8 Dec 80. Ran successful 50% solar test. The clean window performed very well and did not cloud up or get dirty during the test.

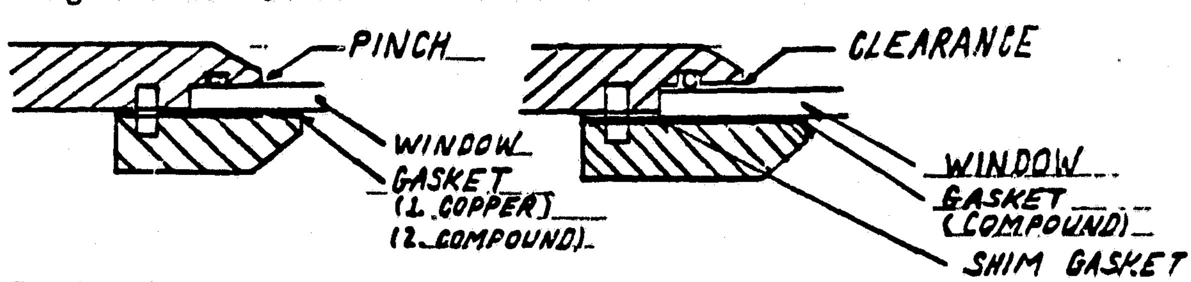
6. 10 Dec 80. Attempted 100% solar test. Window survived for 4 minutes and 30 seconds. Crack then propogated from 2 to 9 o'clock. Numerous small and incomplete cracks developed in upper fragment of window. Window did not burst. Slewed off sun and discontinued test. Inspection showed the window retainer flange had "coned" inward and forced window down against the lip of the window support flange. Increased deformation caused the window to

fracture. On 11 Dec 80 the window retention scheme was modified to allow additional clearance fo the window retainer flange to distort. The retainer flange was shimmed .032" by use of a double gasket. The window is held off the support flange lip by an uncompressed c-ring.

7. 11 Dec 80. Conducted successful 100% solar test. Burner outlet temperature was 900 F. Receiver outlet temperature was 1600 F with solar input. This was the last test conducted at ETS with Sanders (Davis) personnel in attendance. Subsequent testing has taken receiver outlet temperatures up to 2000+ F.

8. 12 Dec 80. Held test review meeting at JPL, Pasadena. Window retention was discussed and the present configuration was deemed fairly optimized for operations up to 2200 F. The necessity for avoidance of stress concentrations when dealing with fused quartz with its unforgiving mechanical properties was emphasized.

The progression of window retention configurations tested during Nov-Dec 80 are shown below.

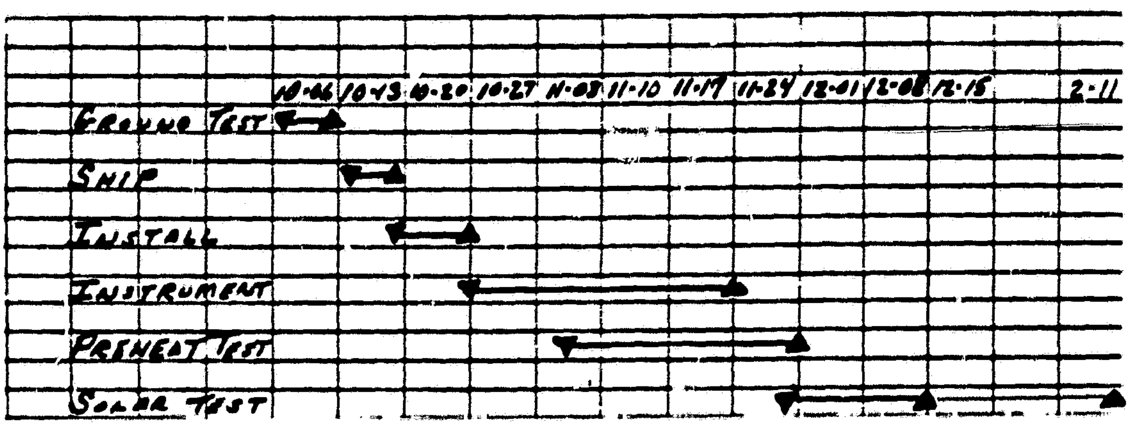


4.5 Auxiliaries

The auxiliary components of the system provided by Sanders (preheater, control console, interface box, control and instrumentation cables) required minimum attention in the

field. Details of PDTS provided utilities such as propane, compressed air, and electric power were tended to by ETS personnel. The only significant item requiring attention was the cooling air line which first had to be increased in size (from 3/8" to 1") and then had to be repaired and supplied with regulated air after it failed.

5.0 CHRONOLOGICAL RECORD



6.0 DATA

The data collected to date has not been reduced or analyzed except for very preliminary measurements. No time has been available to calibrate orifices. Analysis of insulation and housing temperature measurements has not been performed. Power delivered to the aperture is an estimate based on the integration of a flux cross-section taken after

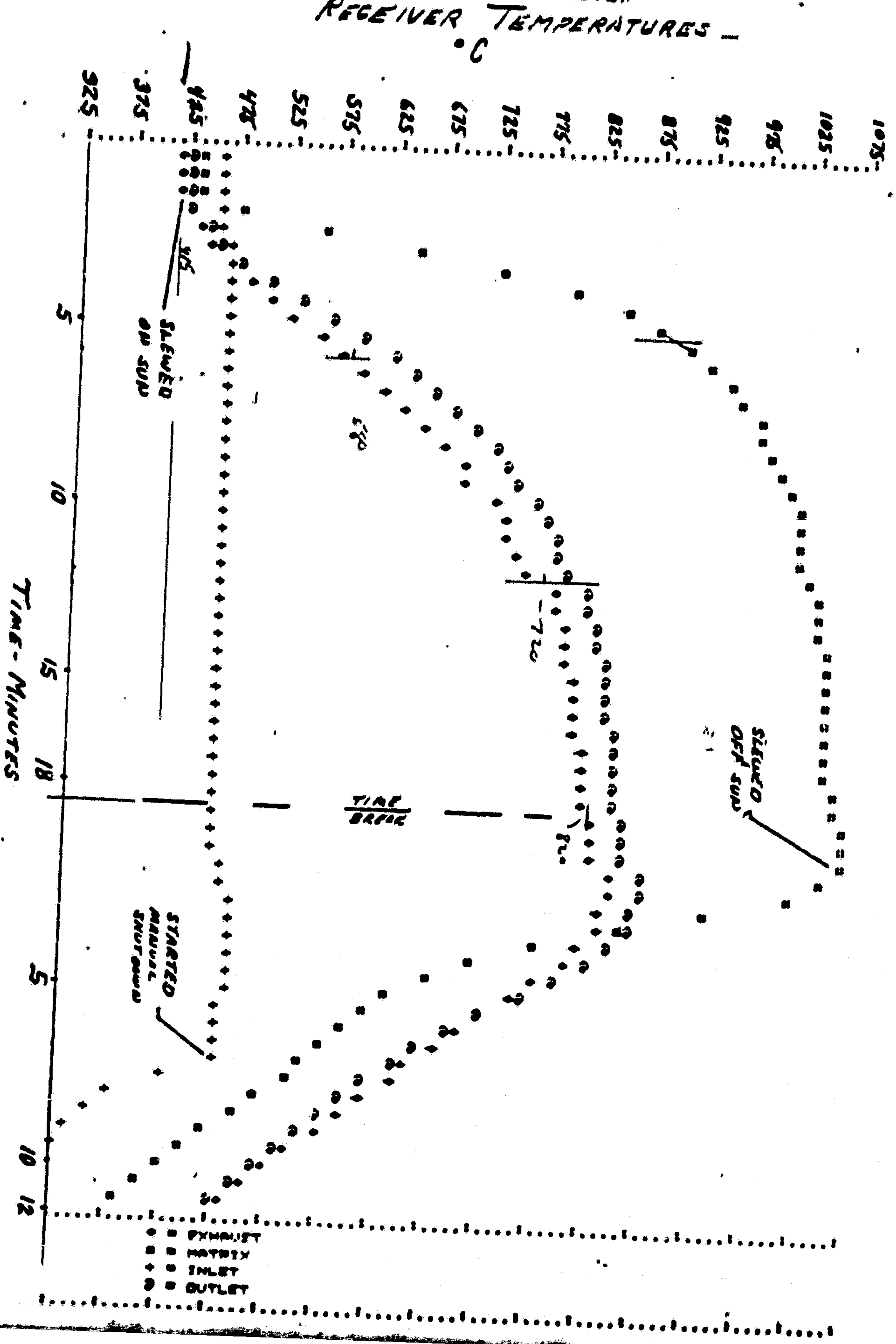
TBC-2 was cross aimed. Efficiency estimates are, at the best, somewhat arbitrary.

With these stated caveats, the following statements are made relative to the performance of the receiver during the 100% solar test conducted on 11 Dec 80.

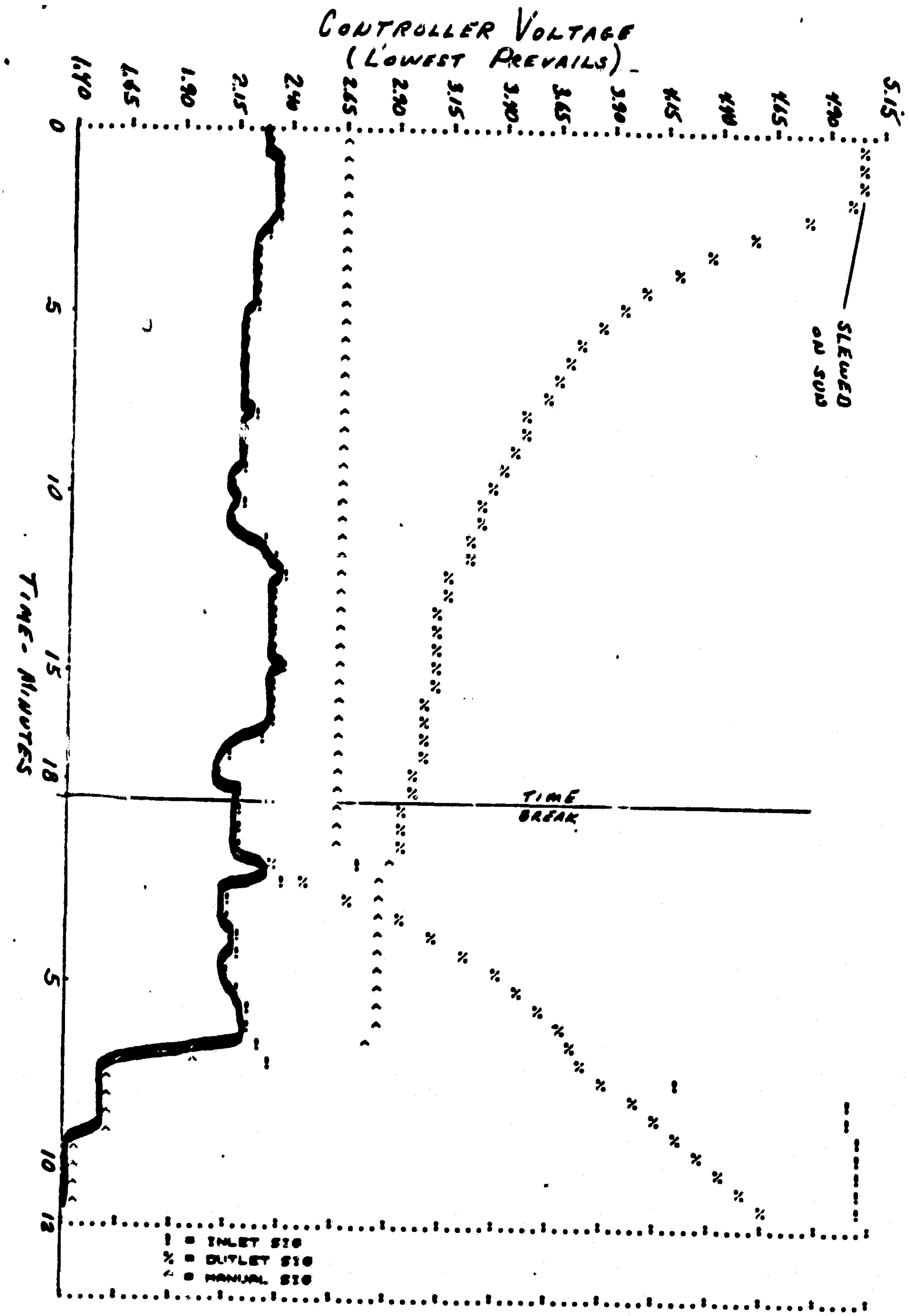
Flow Rate	=	.237	lbm/sec
Average Inlet	=	473.	C
Average Outlet	=	883.	C
Airstream Gain	=	49.6	KW
Power, Solar	=	62.8	KW
Efficiency	=	.79	

Two sets of curves are presented which are typical of the information availble from the data. The first set depicts transient response of the receiver at 100% input. The second set of curves shows the corresponding output of the temperature controllers in response to burner and solar input fluctuations.

"TRANSIENT RESPONSE OF RECEIVER"



"CONTROLLER OUTPUT"



7.0 COMPARISON OF PREDICTIONS AND PERFORMANCE

Thorough comparison of design analysis predictions and measured performance data has not been accomplished to date, as this effort is outside the funded scope of effort.

Any conclusions reached should be regarded as preliminary, because in-depth data reduction which by its very nature is time consuming has been precluded by budget constraints. Nevertheless, we have invested some time in evaluating the agreement between prediction and performance.

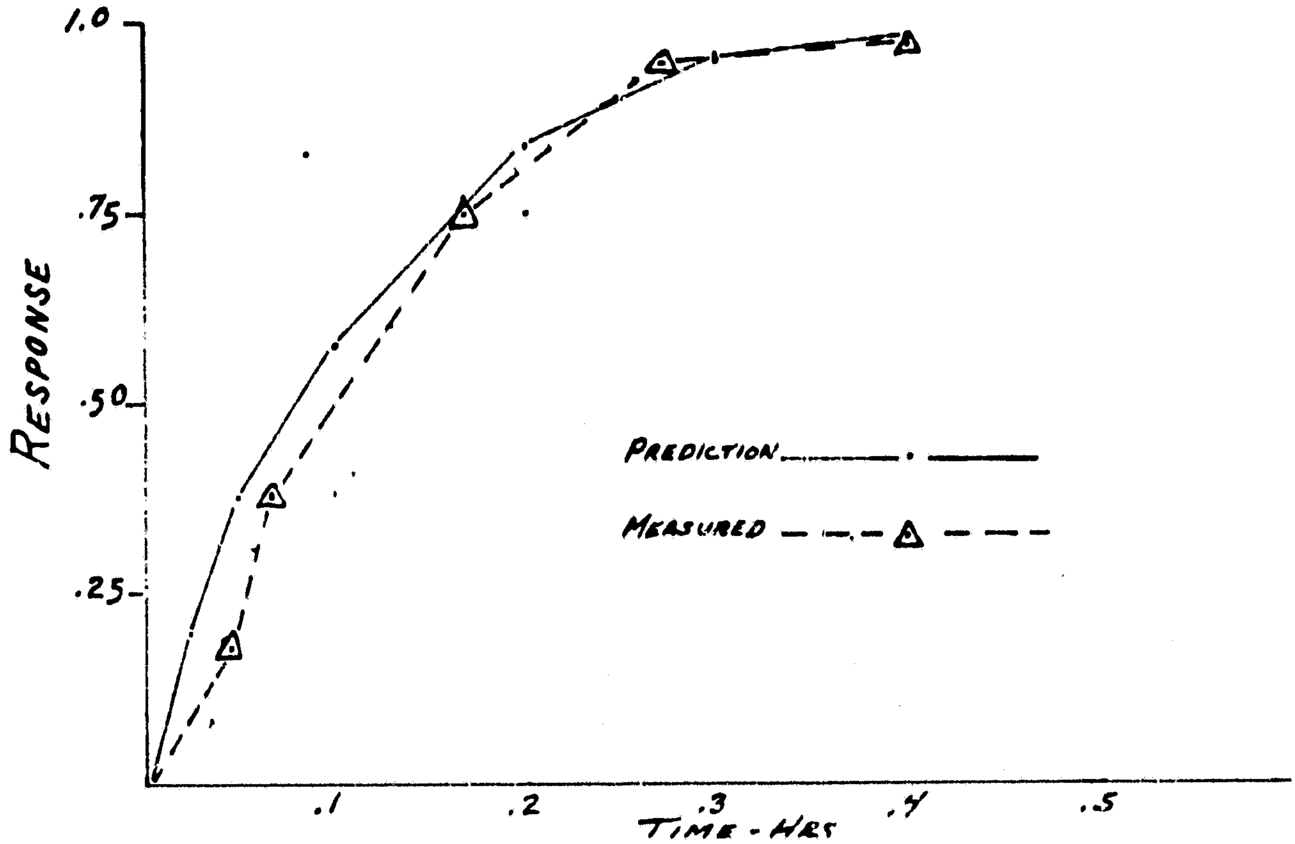
7.1 Window Analysis

The window on which success of the receiver concept pivoted was predicted to survive, and so it did. The design analysis was conducted in a most conservative mode, but all hinged on the real world properties (transmissivity and thermal conductivity) of the (GE-124) quartz as compared to brochure data. The material is in fact more transmissive than the published data, so it may be assumed the data represents a defensible or "warranteed" performance level.

7.2 Transient Response

Response of the system was predicted by use of (ANSYS) finite element modeling to have a 3 time-constant period of .37 hours. Measured data shows the 3 time-constant period was slightly in excess of 19 minutes, or .32 hours. See "Comparative Performance Curves" below.

"Comparative Performance Curves"
Prediction vs Actual



7.3 Efficiency

These comparisons have the greatest uncertainty, because no post test calibration of flow sensors has been conducted. However, several (ANSYS) finite element runs of the system before the fact predicted efficiencies of 79.5% at an outlet temperature of 2350 F to 76.0% at an outlet temperature of 2600 F. The prediction suggests efficiency is not extremely sensitive to outlet temperature.

Preliminary data reduction suggests the efficiency achieved during the 100% solar test conducted on 11 December 1980 was 79.5%. The "measured" performance is in good agreement with the predicted performance, though it may be as much as 5% lower.

8.0 CONCLUSIONS

Obvious conclusions of the program include the demonstrated viability of the design and successful attainment of contract objectives. Less generalized and more specific conclusions relating to future applications of the concept and to future testing are delineated below.

1. Window retention methods are critical to the survival/failure of windows. Stress concentrations must be avoided. The analysis of the window should have included the flange elements rather than questionable boundary conditions. The analytical output,when viewed from the perspective gained during testing, do in fact suggest distortion of the flanges could become a problem.

2. Production cost of the receiver should be well under $3000. or $37.50/kW.

3. The control system worked very well with minimum adaptation required to satisfy program requirements.

4. More complex solar-thermal systems should use an integrated, microprocessor-based control system rather than a collection of multiple discrete contollers.

5. Additional (sufficient) time should be allotted to support adequate engineering support and expediting during critical fabrication phases of programs.

6. Sufficient time should be budgeted to allow the conduct of meaningful data reduction at the end of a program. The squeeze on the final efforts occurs as a result of minor deviations or expansions of effort within the preceding phases of the program. It may be impossible to eliminate this problem entirely, but post test modifications of the program are one avenue available to collect and analyze the findings of worthwhile programs.

7. Structural insulation components used in this receiver, should have been molded rather than being "cut to fit". Time was the principal factor in the cut-mold (make-buy) decision, but sacrifice of some design integrity was necessary to make delivery.

8. At least some ASME boiler requirements can be waived without dire consequences. This is important if not critical to the use of low cost and light weight concentrators.

9. Temperature instrumentation was cost-effective. The use of K-type thermocouples; except where very high temperature R-type were essential; was expedient, economic, and successful.

10. Pressure instrumentation and flow measurement was less than optimum. More attention and more money should have been expended to improve calibration and reliability of the pressure transducers. The added hardware costs would return lower data reduction costs and improved data quality.

9.0 FUTURE_APPLICATIONS

The HTSTR has demonstrated successful high temperature operation and promises long term reliability at temperatures below 1100 C (2000 F). Its simple design and assembly offer low production cost potential and assure its applicability to current requirements. Presently the HTSTR is targeted for EE-2A, the parabolic dish module experiment currently being negotiated by Sanders (et al) and JPL.

More importantly, the low cost potential of the HTSTR can contribute to its deployment worldwide where remote 10-20 kW generators are needed.

Over the past three years we have witnessed the development of significant technology in a joint effort involving government and industry. This developed technology is now ready for integration into systems for subsequent commercialization and extensive deployment.

10.0 RECOMMENDATIONS

The following areas of endeavor would provide data useful to this contract or useful as pertaining to the commercialization of solar thermal systems.

1. Perform additional work in the reduction of collected data.

2. Conduct additional testing for the "Characterization" of receiver performance.

3. Complete the second HTSTR for use in and support of the PDME, EE-2A.

4. Map the current flux distribution near the focal zone of TBC-1 to validate input power assumptions for this experiment and subsequent experiments.

5. Sponsor a quick response integration of the HTSTR and a (Brayton) engine to spur the development of effective control systems and to field an early demonstration of solar thermal electric generation.

6. Study production designs and methods to speed the early commercialization and deployment of these fossil fuel displacing systems.

INDEX